where *ii* is the index on latitude, *jj* is the index on longitude and $I_{ii,jj}$ is the interference power at the satellite from a CPE terminal located at the specified latitude and longitude. The 2 multiplier is present because only 1/2 of the total possible interfering CPEs are simulated, it is assumed that the other half will have an equal contribution to the total interference level.

The configuration of the satellite relative to the CPE equipment and the earth terminal are shown in Figures 1 and 2. Figure 1 depicts the coordinate system along with the position of the Iridium earth terminal transmitting at an predetermined elevation angle (input parameter to the simulation). Figure 2 depicts a distribution of CPE equipment locate on the surface of the earth as viewed from the space vehicle. The CPE equipment are distributed evenly in latitude and longitude throughout 1/4 of the earth that is viewed from the satellite. The spacing of the CPE equipment is in increments of *samwidth* degrees as computed by

$$samwidth = \frac{cellgrid \times diameter}{R_e}$$

where *cellgrid* is a reduction factor of the number of CPE equipment, *diameter* is the diameter of the LMDS cell and R_e is the radius of the earth.

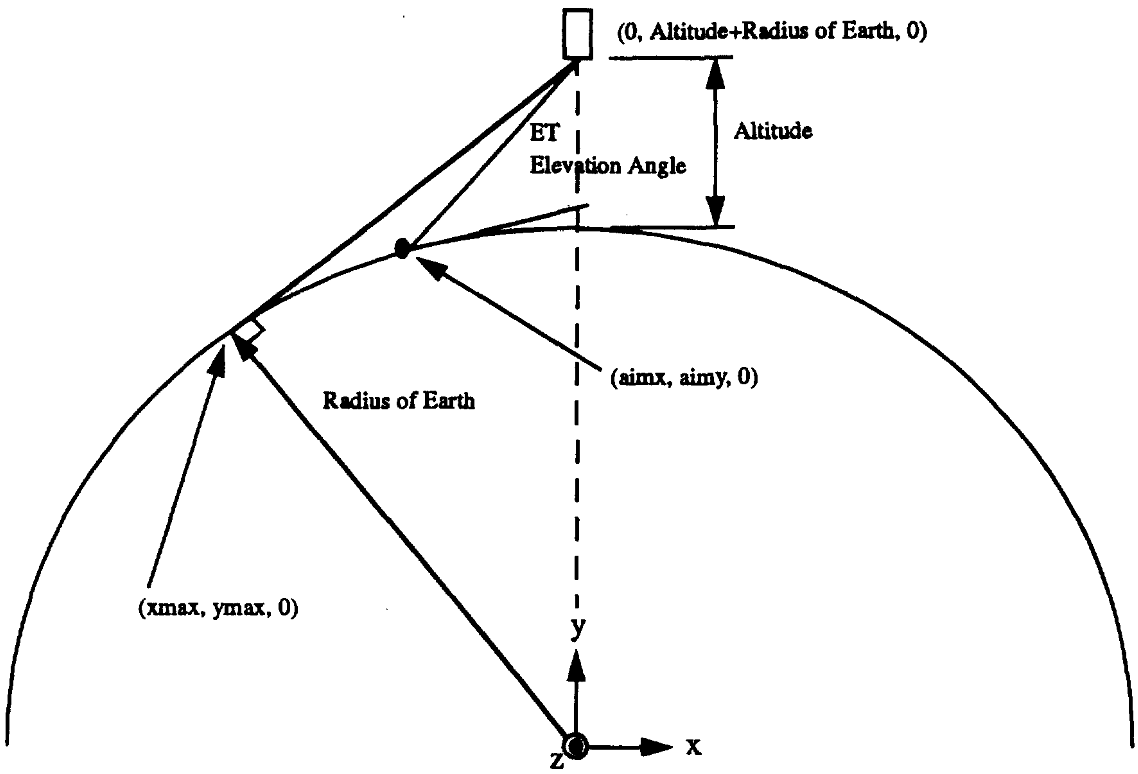


Figure 1. Iridium earth terminal and space vehicle positions.

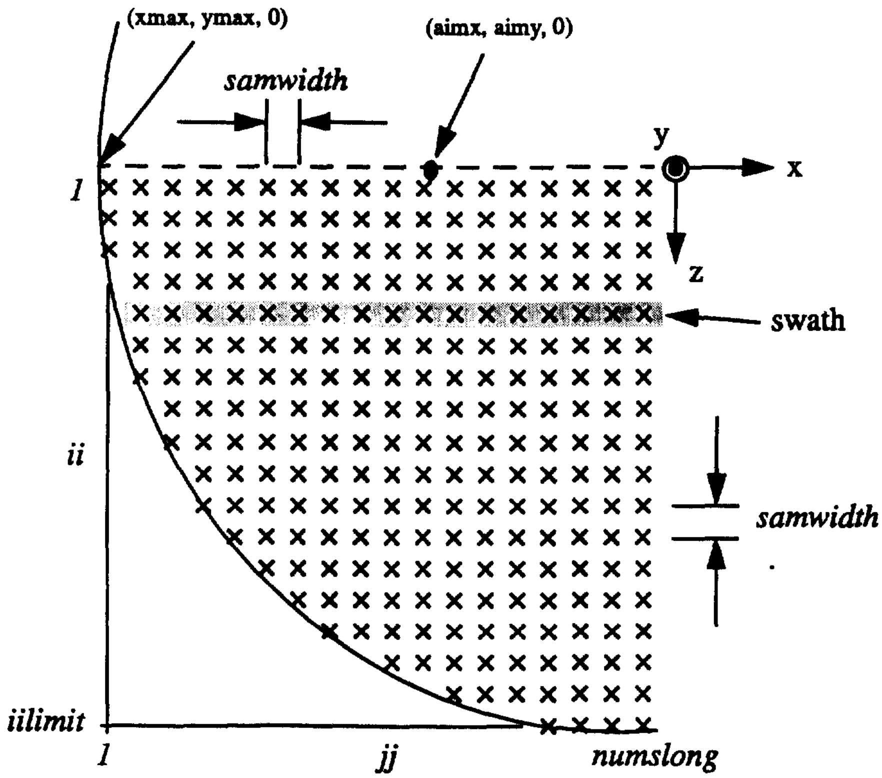


Figure 2. Distribution of CPE equipment.

The contribution from a CPE located at the grid point (*ii, jj*) is

$$\frac{C}{I}_{ii,jj} = eirpleo - (eirplmds + antlmdsg) + xxpol - gridgain + dengain - antleogi + deltap - atmlmdsg$$

where

eirpleo - The transmit EIRP density of the Iridium earth terminal (dBW/Hz).

eirplmds - The LMDS CPE transmit EIRP density (dBW/Hz).

antlmdsg - The modified gain of the LMDS antenna towards the Iridium space vehicle (dB).

xxpol - The cross polarization factor (0 to 3 dB).

gridgain - Reduction factor of the number of grid points actually computed $= 20\log(cellgrid)$. (dB)

dengain - Reduction/incremental factor for sparse/dense areas (dB).

antleogi - Gain of the Iridium space vehicle towards the CPE (dB).

deltap - Space loss factor for the CPE to space vehicle distance and Iridium earth terminal to space vehicle distance (dB)

$$= 20\log\left(\frac{\text{distance between CPE and space vehicle}}{\text{distance between Iridium earth terminal and space vehicle}}\right).$$

antlmdsg - Atmospheric loss between the CPE and Iridium space vehicle (dB).

The hub is assumed to be at an random distance (*lookrange* = square root of a uniform random number from 0 to maximum range of the LMDS system, *maxrange*) from the CPE equipment and at random azimuth angle (uniform distribution from -180 to 180 degrees). The term *antlmdsg* is computed taking into account the elevation and azimuth angles from the CPE to the Iridium space vehicle, power control and a blocking factor

$$anglmdsg = min\,(\text{elevation gain, azimuth gain}) + powercontrol + blockpower$$

in which $powercontrol = 20\log\left(\frac{lookrange}{maxrange}\right)$, *blockpower* is 3 dB if the elevation angle to the LMDS hub is less than 5 degrees, otherwise it is zero.

To account for an increase or decrease in the density of the hubs relative to the halfpower beamwidth of the Iridium space vehicle the variable *dengain* is evaluated as

$$dengain = \begin{cases} 20\log\left(\frac{diameter}{diadens}\right) & \text{in half power beamwidth of SV } and \left(abs\,(ii - dencenswath) \le \frac{denswaths - 1}{2}\right) \\ 0 & \text{in half power beamwidth of SV} \\ 10\log\left(\frac{diameter}{diasparce}\right) & \text{not in half power beamwidth of SV} \end{cases}$$

in which

diadens - The LMDS cell diameter in a dense swath (*diadense* < *diameter*).

diasparce - The LMDS cell diameter outside of the half power beamwidth of the SV (*diasparce* > *diameter*).

denswaths - The number of dense swaths included in the simulation.

dencenswath - The swath in which the dense swaths are centered around.

Note that a swath is the points on Figure 2 corresponding to *ii* being constant.

Input Data

The input data for Iridium is shown in Table 1 and Figure 3.

Table 1: Iridium Input Data

Parameter	Value
Altitude of space vehicle (km)	780
Half power beamwidth (degrees)	5
Elevation angle to the space vehicle (degrees)	7.5
EIRP of the earth terminal (dBW/Hz)	-21.1

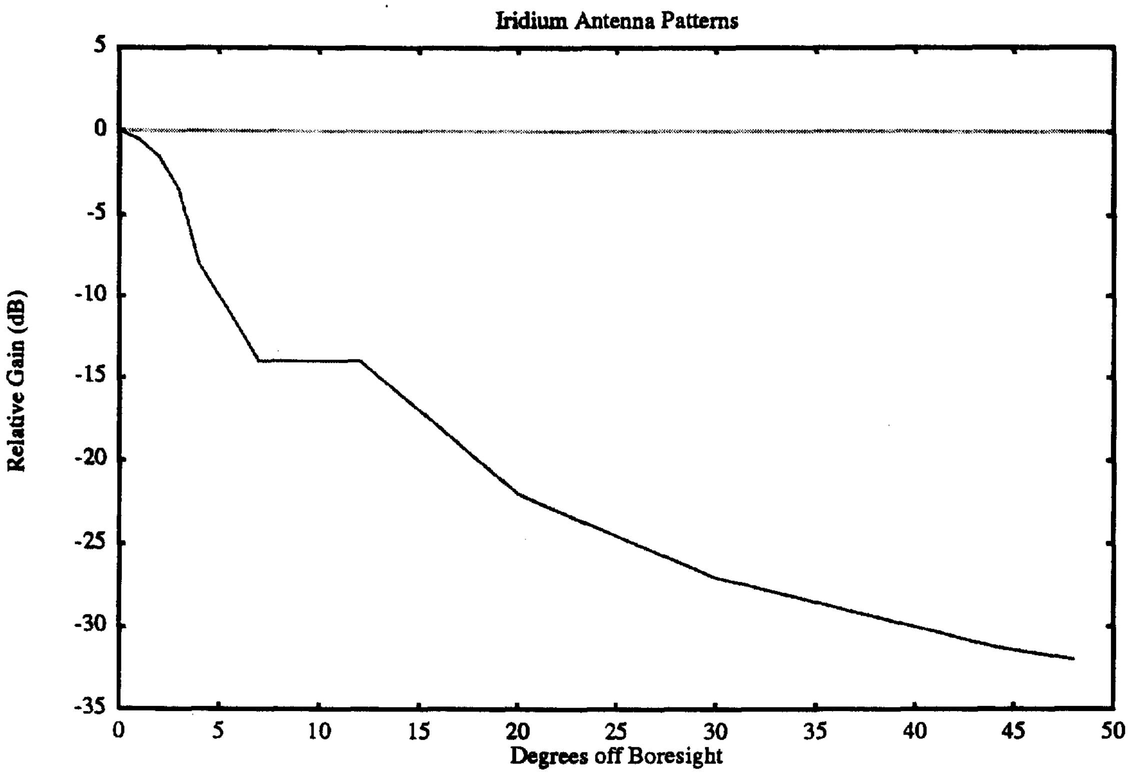


Figure 3. Iridium antenna pattern.

The input data for the LMDS systems are shown in Table 2 and Figures 4 and 5.

Table 2: LMDS Input Parameters

Parameter	Cellular Vision	Endgate Technology	Hewlett Packard	Texas Instruments
EIRP of CPE (dBW/Hz) *eirplmds*	-52	-47.8	-44.6	-47
Cell diameter in 3 dB beamwidth (km) *diameter*	17	17	17	17
Cell diameter out of 3 dB beamwidth (km) *diasparse*	68	68	68	68
Number of dense swaths *denswaths*	0	0	0	0
Swath to center dense areas about *dencenswath*	2	2	2	2
Cell diameter in dense area (km) *diadense*	5	5	5	5
LMDS Hub tower height (m)	30	20	15	30
Maximum cross polarization isolation (dB)	3	3	3	3
Maximum range between hub and CPE (km)	5	2.2	2	5
Maximum elevation angle from CPE to hub for 3 dB blocking (degrees)	5	5	5	5

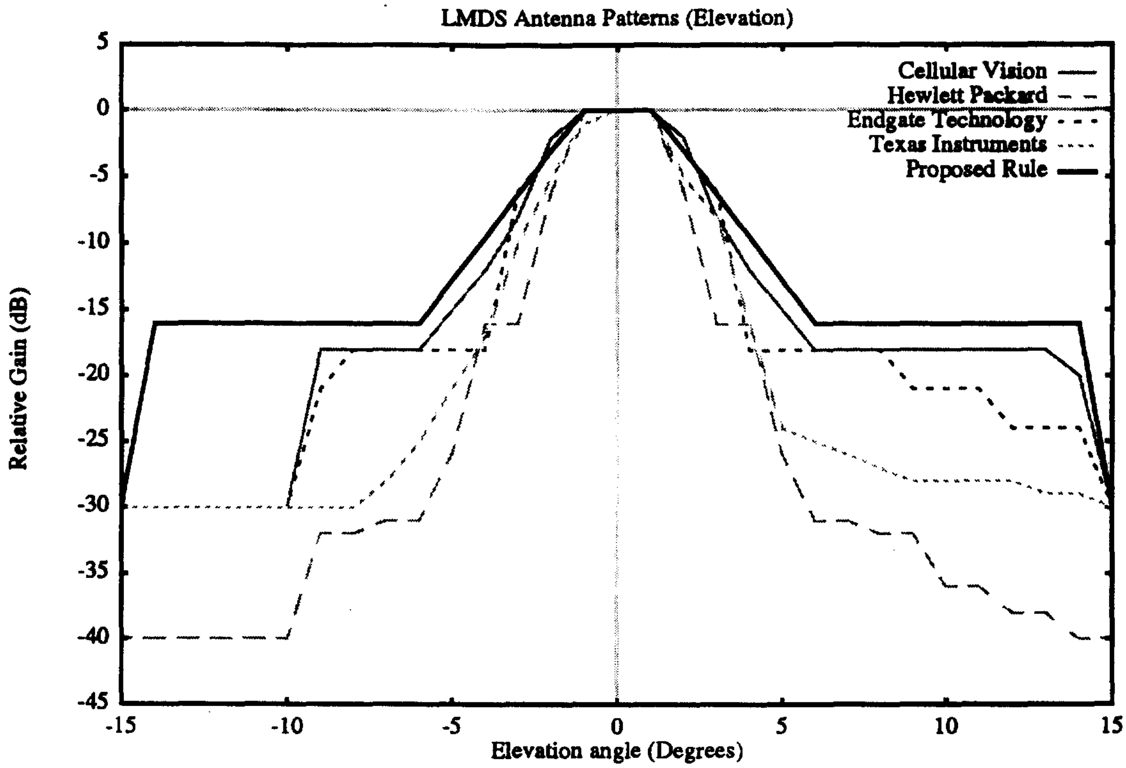


Figure 4. LMDS CPE elevation antenna patterns.

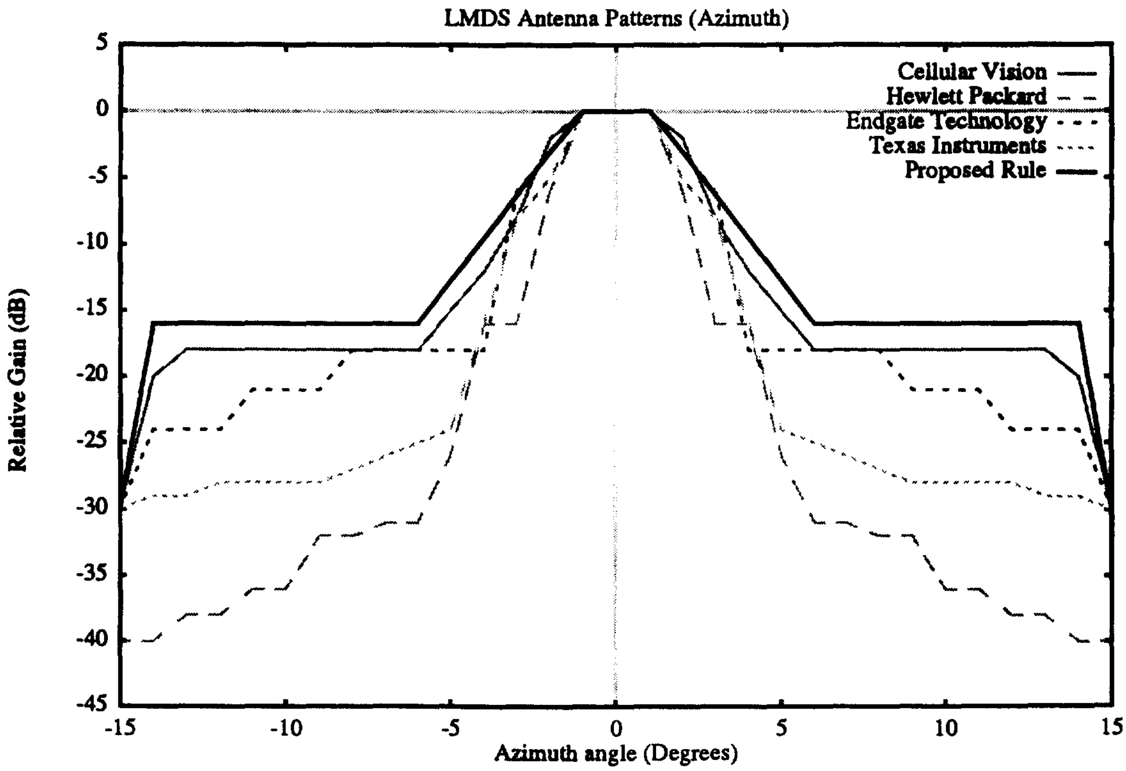


Figure 5. LMDS CPE azimuth antenna patterns.

Figure 6 shows the atmospheric attenuation plotted against the elevation angle.

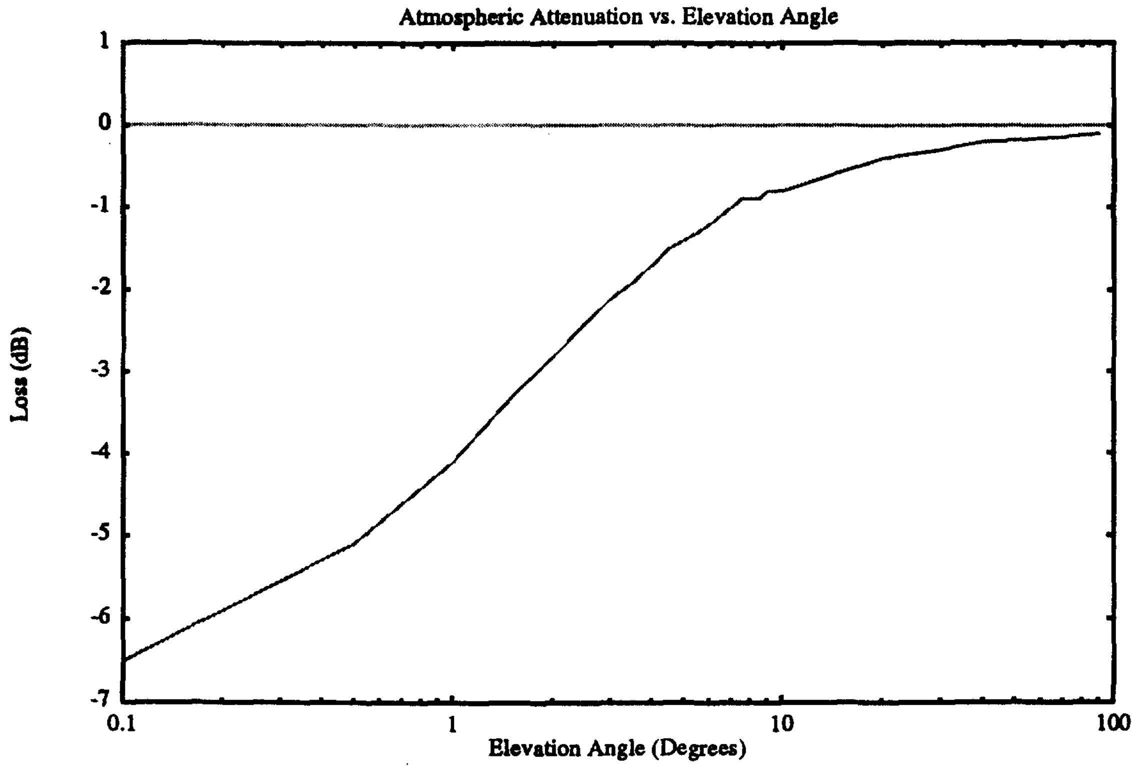


Figure 6. Atmospheric attenuation vs. elevation angle.

Examples

Randomness of the results

To illustrate the variation of the results due to insufficient number of CPEs within the mainbeam of the Iridium space vehicle the simulation was ran 100 times with different seeds to the random number generator. This allows the variance of the model to be quantified. The LMDS system used is the one proposed by Texas Instruments. Figure 7 shows the distribution of the C/I ratio for the 100 runs quantized into 20 bins ranging from the minimum computed C/I level (28.6 dB) to the maximum computed C/I level (36.6 dB), the data had a mean of 33.25 dB with a variance of 4.42. Note that the simulation used over 4 hours of cpu time on SUN Sparc 10 computer, and that this relatively small sample does not represent the true distribution of the results if many more samples were taken. It should also be noted that 30% percent of the time the total C/I ratio is within +-0.5 dB of the 35.4 dB quoted in TIs letter, but 12% of the time the level is less than or equal to 30.0 dB.

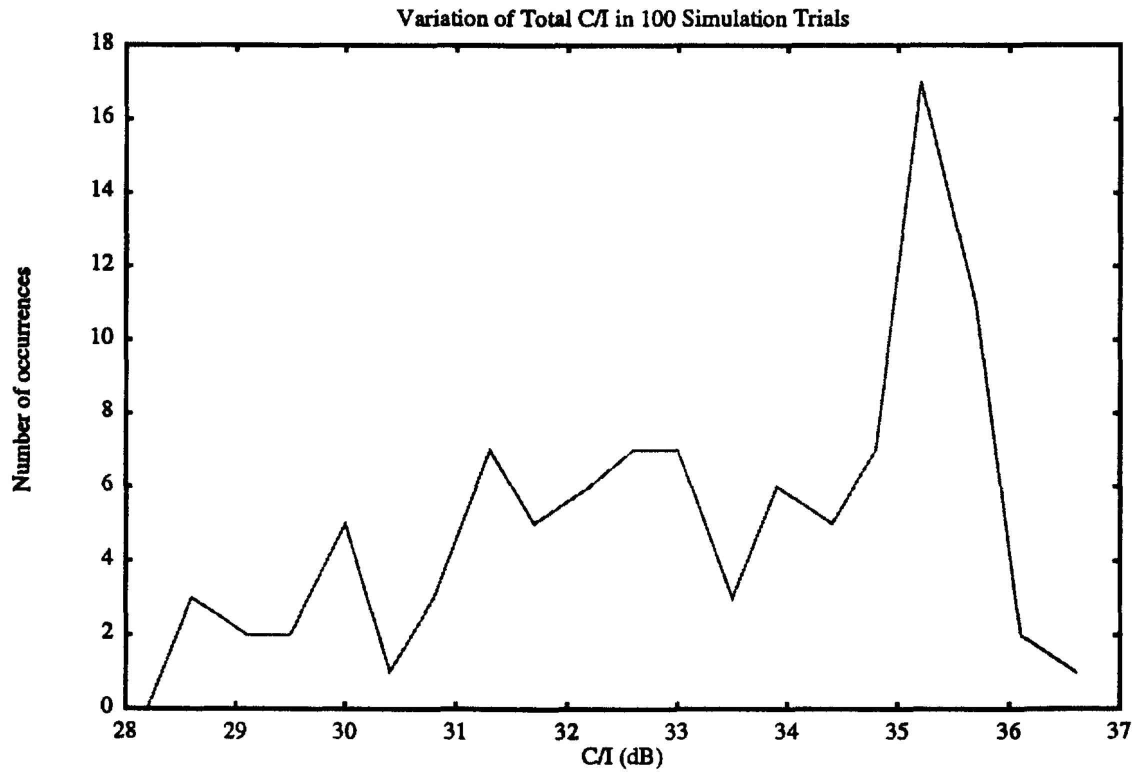


Figure 7. Histogram of C/I.

Results in terms of Io/No

To avoid the impact of the operations of the Iridium systems implementation of power control it is preferred to analyze the interfering systems in terms of the interference to noise ratio. The program was modified to compute I_0/N_0. Additional Iridium system parameters are shown in Table 3.

Table 3: Iridium System Parameters

Parameter	Value
Frequency	29.1 GHz
Maximum receive antenna Gain	30.1 dBi
Receiver Noise Density *rxno*	-197.48 dBW/Hz

The interference to noise ratio is computed by

$$\frac{I_0}{N_0} = \sum_{ii=1}^{iilimit} \sum_{jj=1}^{numslong} \frac{2I_{ii,jj}}{N_0}$$

The contribution from a CPE located at the grid point (*ii, jj*) is

$$\frac{I_{ii,jj}}{N_0} = eirplmds + antlmdsg$$
$$-xxpol + gridgain - dengain$$
$$+ antleogi - deltap + atmlmdsg - rxno$$

where all variables are the same as above except for

deltap - Space loss factor for the CPE to space vehicle (dB)

$$= 20\log\left(\frac{4 \cdot \pi \cdot \text{distance between CPE and space vehicle}}{\lambda}\right)$$

in which λ is the wavelength of operation.

rxno - Receiver noise density.

The simulation was run again to compute the interference to noise level. There were 339 trials that used 12.3 hours of computer time to arrive at the results shown in Figure 8. The mean I_0/N_0

is -16.96 dB with a variance of 4.06, a minimum of -19.8 dB and a maximum of -10.7 dB. There were 18 trials that resulted in the interference to noise level of greater than or equal to -13 dB (5.3% of the trials).

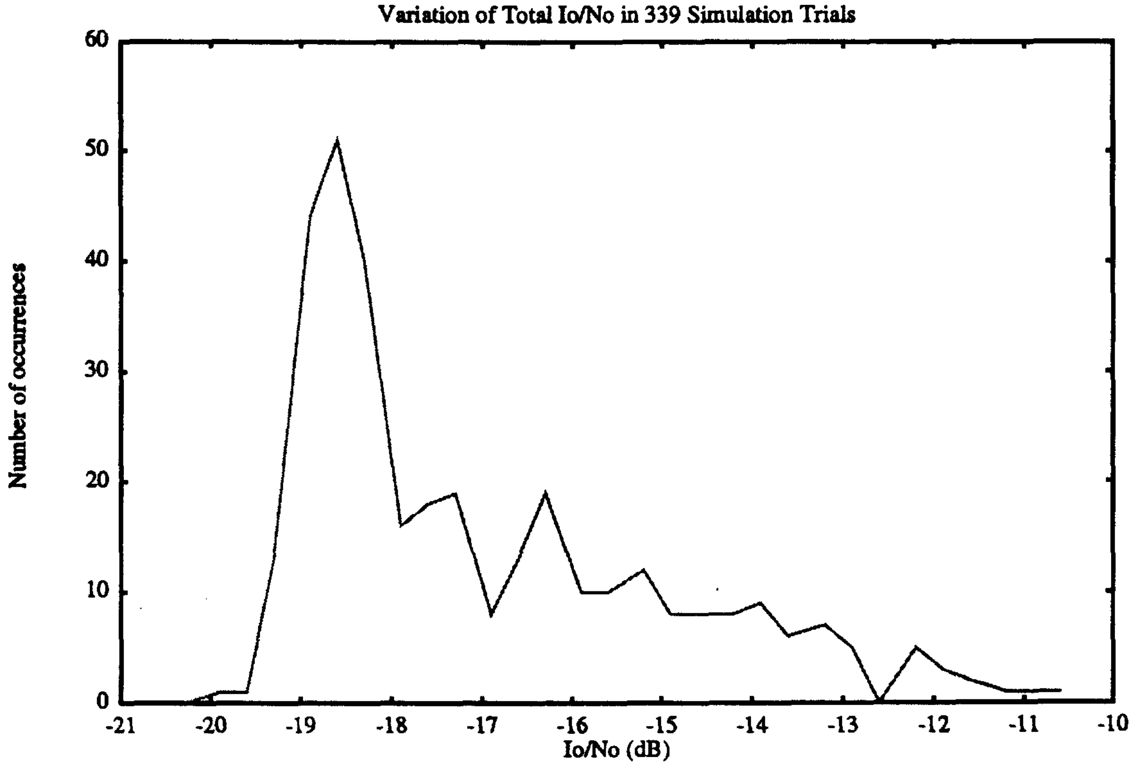


Figure 8. Histogram of Io/No.

Simulating worst case CPE associated with hub

The analysis assumes that the azimuth angle from the boresight of the CPE to the satellite is a random number that ranges from -180 to 180 degrees, this assumption has the effect of reducing the likely hood that a CPE will cause interference to the Iridium satellite. Consider Figure 9 that shows a LMDS hub with a frequency reuse factor of 4. If the azimuth angle from the CPE to the satellite is assumed to be random in the range from -180 to 180, the CPE is equally likely to fall in any sector associated with the hub. The CPE that will cause the most interference is located in Sector 3. Therefore, the simulation under estimated the interference level when it assumed that the CPE is randomly located in any sector. To accurately represent the interference associated with this hub the simulated CPE equipment should fall in Sector 3, thus the azimuth angle to the satellite should be restricted to fall in the range -180/*nsect* to 180/*nsect*, where *nsect* is the number of sectors in the hub antenna (i.e. the frequency reuse factor).

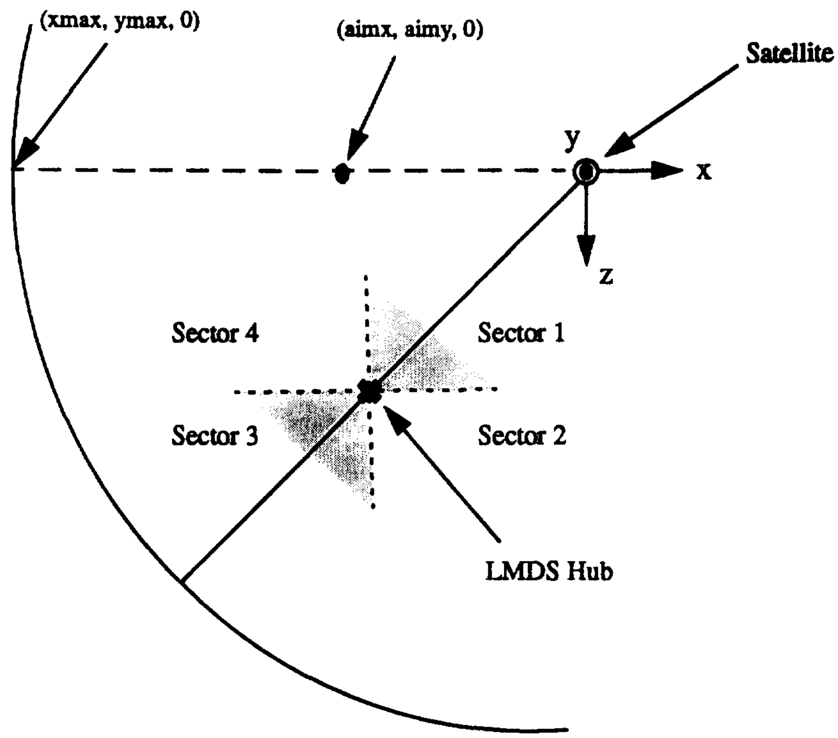


Figure 9. Simulating largest interfering CPE.

Shown in Figure 10 is the effect of this on the interference to noise ratio on 1000 trials (40.2 hours of computer time). The mean interference to noise level is -13 dB with a variance of 4.15, a minimum of -18.0 dB and a maximum of -7.9 dB. There were 531 trials that resulted in the interference to noise level greater than or equal to -13 dB (53.1%) and the 99 percentile of interference to noise level is -8.8 dB.

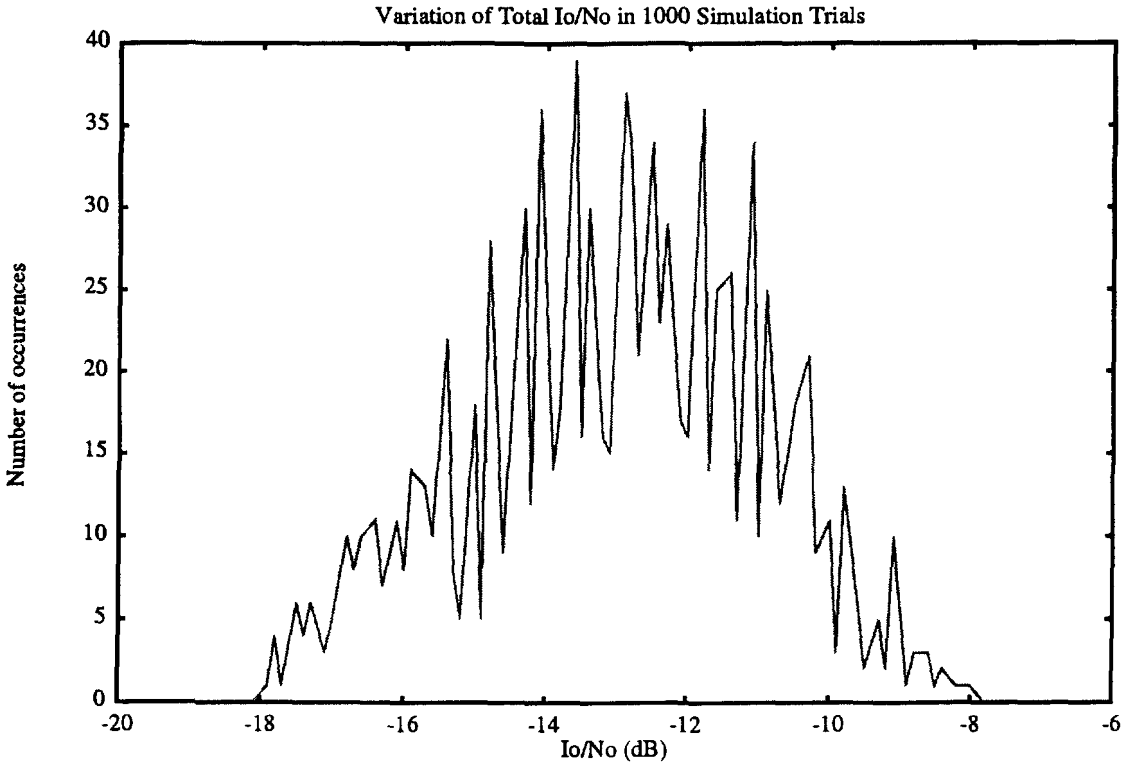


Figure 10. Histogram of Io/No when simulating most likely interferer.

<u>Other effects</u>

Other effects that the analysis simulates but was not demonstrated in the results presented to Motorola are:

1) Power Control - The analysis assumes that power control is used based on the range between the CPE and the hub. This is misleading because the blockage that is causing propagation loss between the CPE and the hub is not the same as between the CPE and the Iridium space vehicle. To assess the worst case impact to the Iridium feeder links it should be assumed that the blockage between the CPE and the hub is modeled via a accepted propagation model (i.e. Okamura-Hata) and that it is assumed that there is clear line-of-sight between the CPE and the satellite. The time allowed did not permit the above suggestion to be modelled, but the analysis did allow no power control to be used. This option assumes that the minimum power transmitted at the edge of coverage to close the link is the same transmit power for all CPE in the coverage region.
2) Dense swaths - The data file sent to Motorola had the dense swath option set to 0, thus allowing no dense areas. This option was set to 1 and the corresponding option that set which swath that a dense area may occur is set to 1.
3) The analysis has a 3 dB blocking factor if the elevation angle to the hub is less than 5 degrees. This blocking factor falls under the power control and is set to zero in the simulation.

Shown in Figure 11 is the effect of the above points on the interference to noise ratio on 525 trials (20.9 hours of computer time). The mean interference to noise level is 0.8 dB with a variance of 7.27, a minimum of -4.4 dB and a maximum of 7.4 dB.

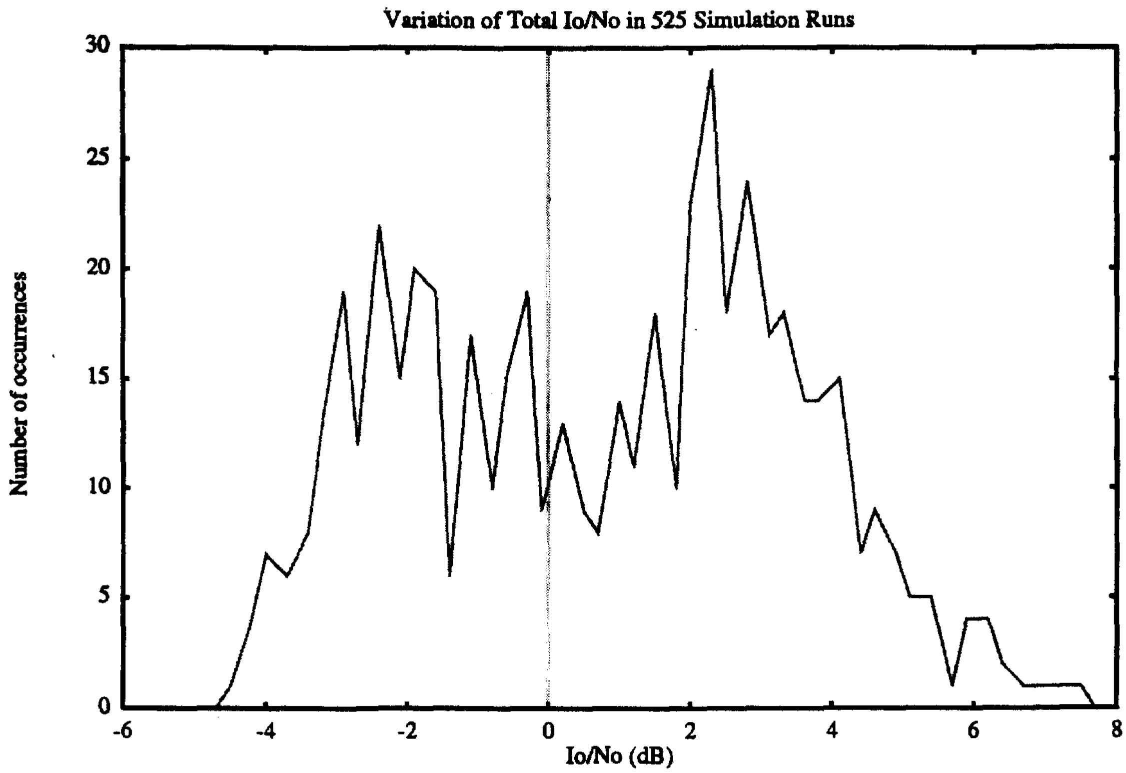


Figure 11. Histogram of Io/No with 1 dense swath and no power control.

Interference levels from Proposed Rules

Texas Instruments have proposed the following rules[1]:

1) For systems that do not employ power control the maximum EIRP is 14 dBW/MHz (-46 dBW/Hz)
2) For systems that employ power control the maximum EIRP (P in dBW/MHz) is given by
   $P = 20 + 20 \log (d/D)$
   where d is the transceiver distance to hub and D is the maximum distance to hub.
3) The antenna patterns (in azimuth and elevation) show as "Proposed Rule" in Figures 4 and 5 shall be met at all times.

Shown in Figure 12 is the interference to noise ratio for a system satisfy the above items 1 and 3, along with the same assumptions that were made to produce Figure 11. The mean level of interference is 6.85 dB with a variance of 2.0, a minimum of 2.1 dB and a maximum of 10.0 dB.

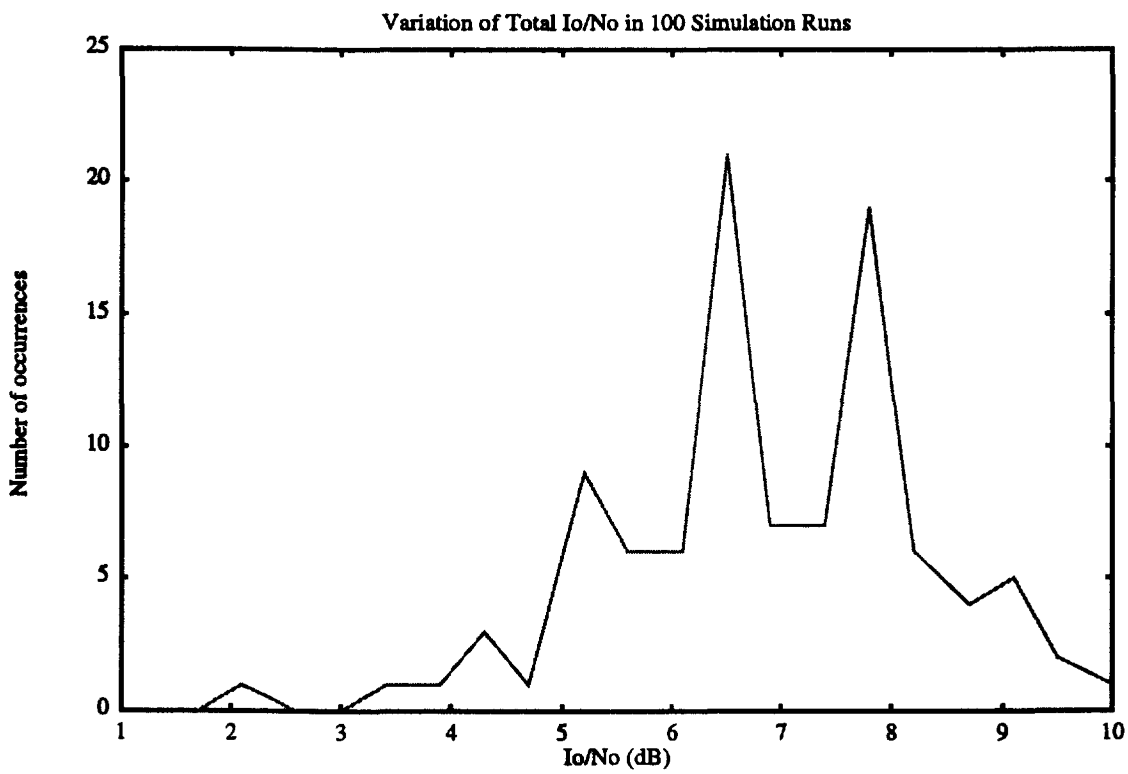


Figure 12. Histogram of Io/No for proposed rules (no power control).

1. Facsimile Transmittal from Gene Robinson to John Knudsen, October 30, 1995.

Shown in Figure 13 is the interference to noise ratio for a system satisfy the above items 2 and 3, along with the same assumptions that were made to produce Figure 11 (this time including power control on the range between the CPE and the hub). The mean level of interference is 9.72 dB with a variance of 2.4, a minimum of 5.3 dB and a maximum of 12.9 dB

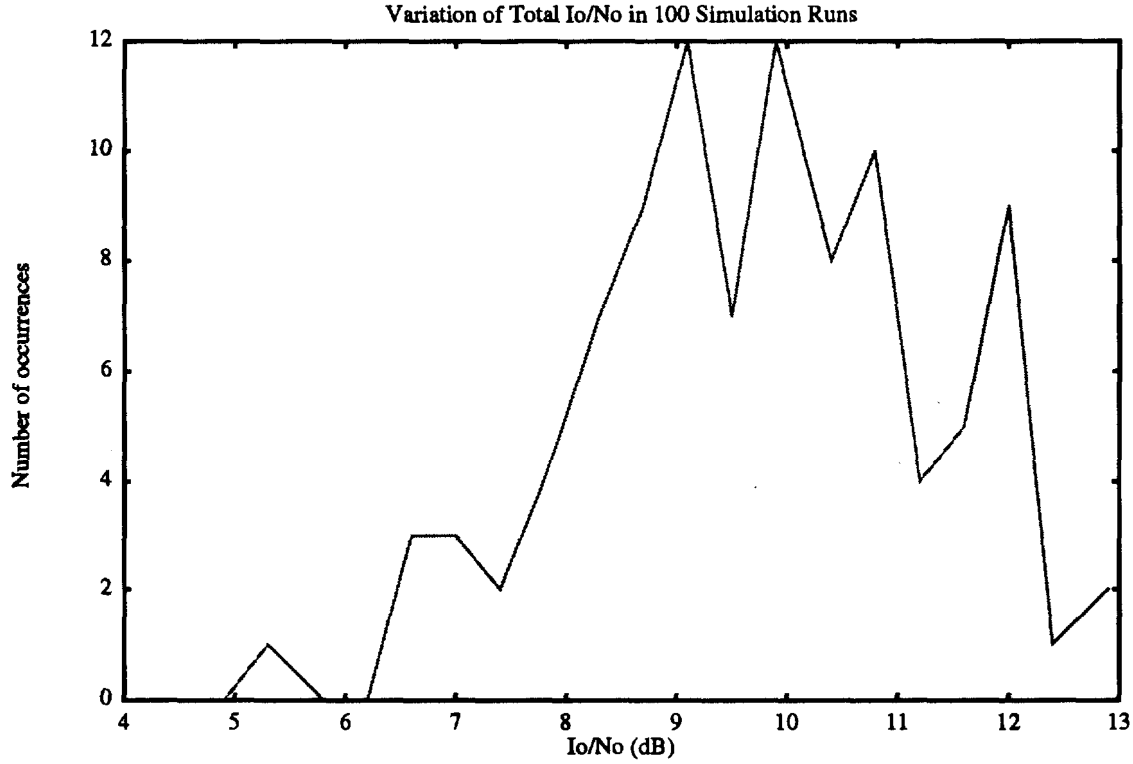


Figure 13. Histogram of Io/No for proposed rules (no power control).

DENSITY

- SV Footprint Population Base NE & Mid-Atlantic — 75 million
  - Households, 3 per household — 25 million
  - LMDS Coverage 0.8 — 20 million
  - Subscribers (Take Rate, 25%) — 5 million
    - 4:1 Concentration — 1.25 million

- Subscribers per MHz for 150 MHz

$$\frac{1.25 \times 10^6}{150\ \text{MHz}} \qquad 8333$$

- Number of Circuits per MHz
  - data rate for DS0 64Kbs
    eff. of 0.6 — 890*

* Maximum loading exclusive of sub sectors ?

- Number of systems pointing in the direction of the satellite.

$$890 \times \frac{\text{CPE Beamwidth}}{360^\circ}$$

$$890 \times \frac{4}{360} = 9.9 \sim \boxed{10}$$ Subscribers per MHz

LMDS PARAMETERS

- TRANSMIT EIRP — -40 dBW/Hz
- Space Loss

@ 2747 Km, 5° EL		-189.6 dB
@ 780 Km, 90° EL		-179.6 dB

LMDS Sig Level	I @SV Ant	I_o @SV Rec
@ 2747 Km		
-40 -189.6	-229.6	-[redacted]
@ 780 Km		
-40 -179.6	-219.6	-189.4

SATELLITE/GATEWAY PARAMETERS

- Gateway Transmitter EIRP 43.2 dBWi
- Spaceloss at
  - 2747 Km, 5° EL -182.6 dB
  - 780 Km, 90° EL -172.6 dB
- Satellite Antenna Gain 30.1 dB
- Satellite Rec. Noise Floor, N_0 -197.5 dB
- Satellite Sig Level

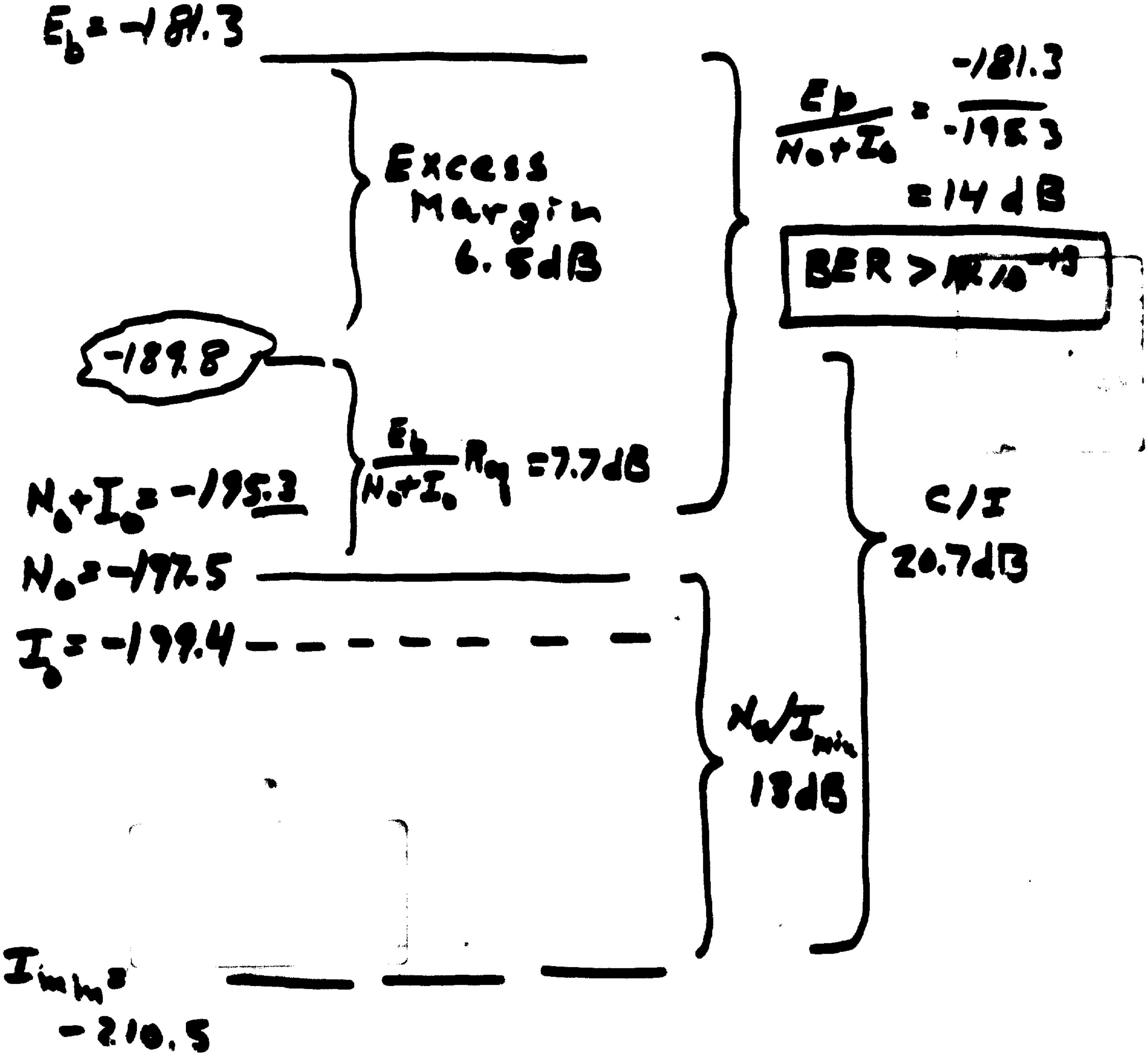
		@ Ant.	@ Rec
@ 2747 Km	43.2-182.6 →	-146.4	-116.3
@ 780 Km	43.2-172.6 →	-136.4	-106.3

- Data Bit Rate ; 1/2 Rate
  - Code rate 6.25 MB/s
  - Info rate of 3.125 MBPS -65 dB
- Satellite Receiver, E_b

@ 2747 Km $E_b = (-116.3) + (-65) = -181.3$

@ 780 Km $E_b = (-106.3) + (-65) = -171.3$

MAX RANGE / MIN SIGNAL
(2747 Km / -181.3 dB)



MAX RANGE
MULTIPLE CPE's

- $I_o' \Rightarrow 10$ CPE's ; 100% at max Range

$I_o' = I_o + 10\,dB = -199.4 + 10 = -189.4$

$I_o' + N_o = (-189.4) + (-197.5) = -188.7$

$$\frac{E_b}{N_o + I_o'} = \frac{-181.3}{-188.7} = 7.4\,dB$$

BER = 0.8×10^{-8}

- $I_o'' \Rightarrow 5$ CPE's ; 50% blockage at max Range.

$I_o'' = I_o + 7\,dB = -199.4 + 7 = -192.4$

$I_o'' + N_o = (-192.4) + (-197.5) = -191.2$

$$\frac{E_b}{N_o + I_o''} = \frac{-181.3}{-191.2} = 9.9\,dB$$

BER = 1×10^{-12}

MIN RANGE / SIGNAL
(780 Km / -171.3)

$E_b =$
-171.3

$$\frac{E_b}{I_o + N_o} \quad \frac{-171.3}{-188.8} = 17.5\,dB$$

BER > 1x10$^{-\infty}$

$I_o + N_o = -188.8$

I_o
-189.4

$N_o = -197.5$

$$\frac{E_b}{N_o + I_o} = \frac{-171.3}{-188.8} = 17.5\,dB$$

BER > $1 \times 10^{-\infty}$ ✓

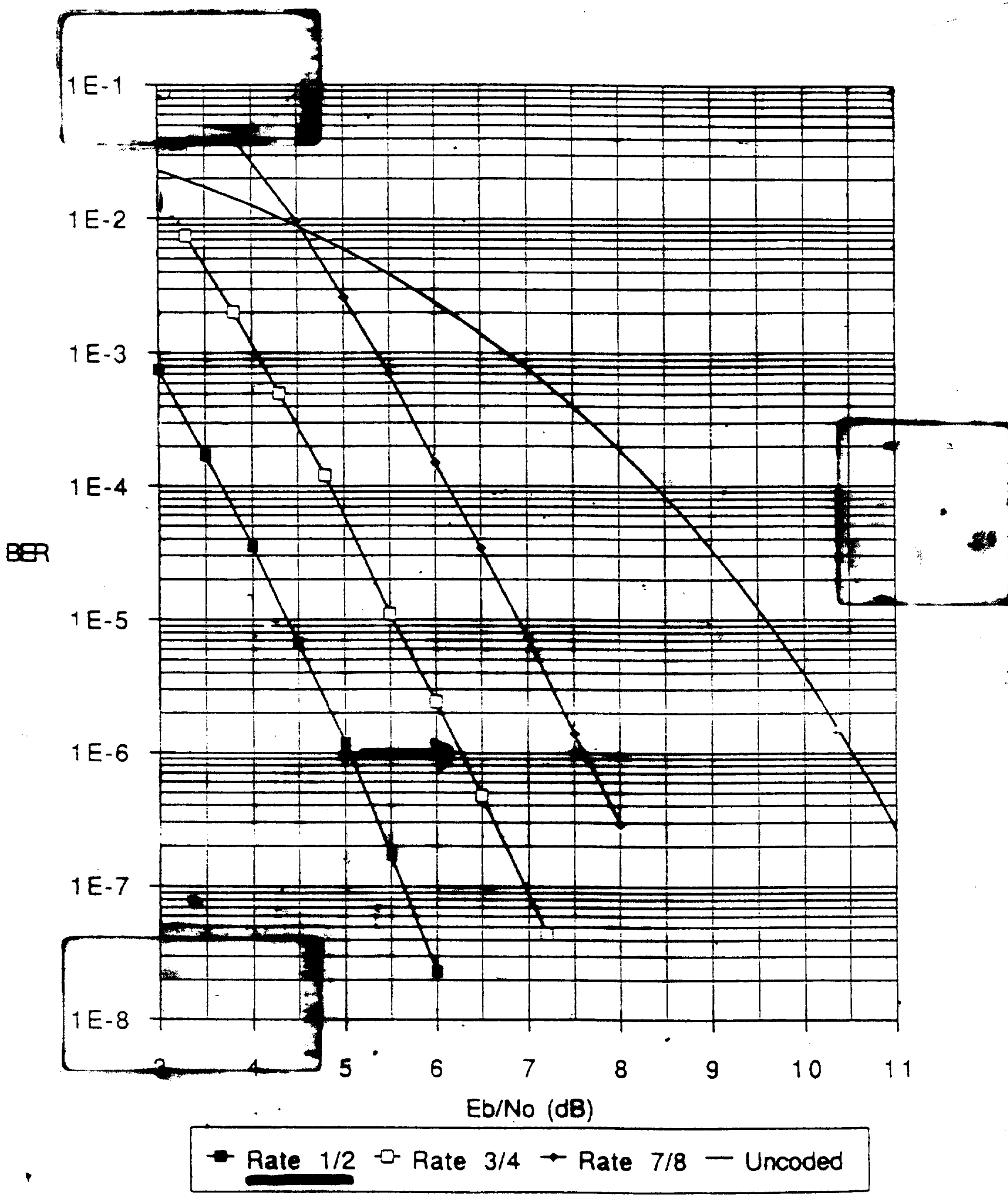
- $I_o' > 10$ CPE's

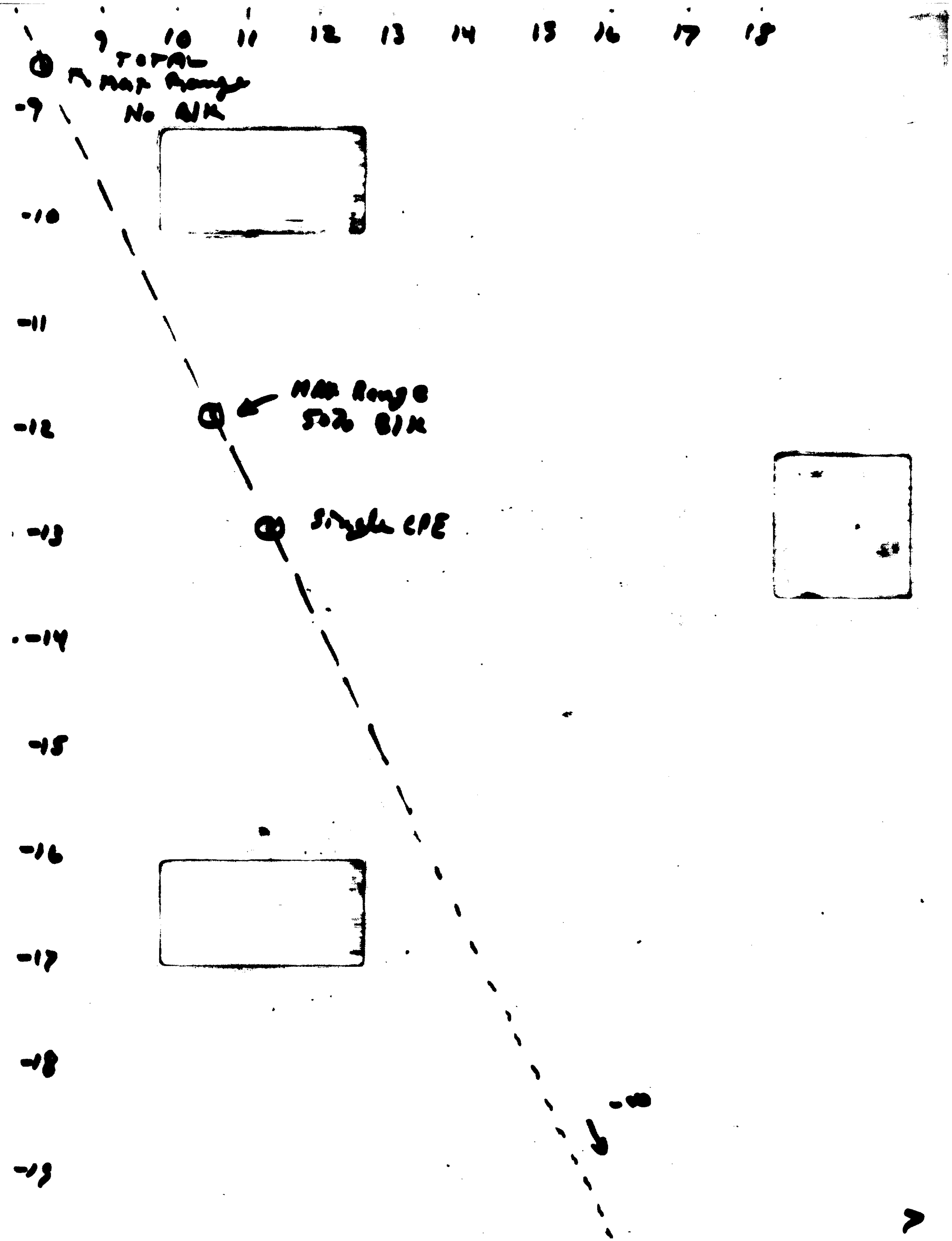
$I_o' = I_o + 10 = -189.4 + 10 = -179.4$

$N_o + I_o' = (-197.5) + (-179.4) = -179.3$

$$\frac{E_b}{N_o + I_o'} = \frac{-171.3}{-179.3} = 8\,dB$$

BER $= 0.6 \times 10^{-9}$ ✓


1 E-1
1 E-2
1 E-3
1 E-4
1 E-5
1 E-6
1 E-7
1 E-8
BER
3
4
5
6
7
8
9
10
11
Eb/No (dB)
Rate 1/2
Rate 3/4
Rate 7/8
Uncoded


9 10 11 12 13 14 15 16 17 18
TOTAL
% Max Range
No B/K
Max Range
50% B/K
Single CPE
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-∞